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Inventors:	Ronald S. Cok
Attorney:	Thomas H. Close

CIRCUIT FOR DETECTING AMBIENT LIGHT ON A DISPLAY

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P. O. Box 1450
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CIRCUIT FOR DETECTING AMBIENT LIGHT ON A DISPLAY

FIELD OF THE INVENTION

The present invention relates to photosensor circuits and more particularly to solid state flat panel displays having photosensors for sensing ambient illumination.

BACKGROUND OF THE INVENTION

Flat panel displays such as liquid crystal displays (LCDs) or organic light emitting diode (OLED) displays are useful in a wide variety of applications under a wide variety of environmental conditions. When viewed in a dark environment (little ambient radiation), such displays need not be as bright as when viewed in a lighter environment (more ambient radiation). If the display light output is adjusted periodically to compensate for ambient light conditions, the display can maintain a fixed ratio between the ambient and displayed light even if the ambient light changes. This can, in turn, increase display brightness to improve visibility in a bright environment and increase display device lifetime and reduce power usage by reducing unnecessary display brightness in a dark environment.

The use of photosensors with displays to detect ambient light and adjusting the brightness of the display in response to ambient illumination is known. Efficient silicon photosensors are available and generally provide a current proportional to the light incident on the sensor. These photosensors are constructed on silicon substrates. Such sensors can be combined with displays to provide ambient sensing. For example, see JP2002-297096-A, which describes a circuit for providing ambient compensation to an electroluminescent display. However, as implemented, the sensor is separate from the display and senses the light at a single point. This increases the cost, number of components, and size of the device; reduces the sensitivity of the sensor; and does not directly measure the light incident on the display itself.

It is known to integrate a light sensor on an active-matrix display device for the purpose of sensing light emitted from the display device itself. See for example, US 6,489,631 issued December 3, 2002 to Young et al., which describes a display having integrated photosensors for sensing light emitted by a light emitting element of the display. However, the arrangement of the sensor coupled with a light emitter limits the size of the photosensor and its ability to sense ambient light. Moreover, such photosensors constructed on flat panel displays do not have the efficiency of those constructed on silicon substrates and do not have the sensitivity necessary to provide a signal representative of lower light levels, for example < 100 cd/m2, where displays are often used. Hence, alternative circuits and designs are necessary.

When providing ambient compensation to a display, it is important that the light sensing device provide a continuously valid output that is always representative of the ambient illumination. If, instead, the output is periodically invalid, any compensation will be periodically incorrect and may cause flicker in the display. Alternatively, additional circuitry must be added to sample and hold the output of the light sensing device. Moreover, it is advantageous to provide a signal output that is representative of the ambient illumination over a range of light levels.

There is a need therefore for an improved photosensor for the detection of ambient light within an active matrix flat panel display.

SUMMARY OF THE INVENTION

The need is met according to the present invention by providing a circuit for detecting ambient light on a display that includes a light integrating photosensor circuit having a photosensor and being responsive to ambient light for periodically producing successive photo signals representing the intensity of the ambient light; and an averaging circuit for receiving the successive photo signals and producing an average ambient light signal representing a continuous running average of the successive photo signals.

ADVANTAGES

The advantages of this invention are an improved photosensor circuit for ambient compensation in low light conditions that can be readily integrated within an active matrix flat panel display.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic block diagram of a photosensor circuit according to the present invention;

Fig. 2 is a schematic circuit diagram of one embodiment of the photosensor circuit of Fig. 1;

Fig. 3 is a timing diagram useful in describing the operation of the circuit of Fig. 2; and

Fig. 4 is a schematic diagram of an embodiment of a photosensor circuit and display device according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring to Fig. 1, the present invention includes a circuit **8** having a photosensor **10** connected to a detection circuit **11**. The detection circuit **11** and photosensor **10** form a photosensor circuit **12** that is connected to an averaging circuit **14** comprising a storage circuit **13** and an output circuit **16**. The photosensor **10** may be any light-sensitive device suitable for use within a display system. For example, silicon or organic photodiodes or transistors may be employed. These photosensors and circuit elements may be discrete or, preferably, are integrated with a display to provide an integrated solution. When integrated with a display, any portion of, or all of, the circuit **8** may be constructed using thin film transistors and electrical components as are known in the flat panel display art. Display substrates may be made of rigid or flexible glass or plastic.

Referring to Fig. 2, a more detailed circuit diagram is shown. The photosensor **10** has two terminals, one of which is connected to a given voltage, for example ground, the other of which is connected to the drain of an isolation transistor **30**. The gate of the isolation transistor **30** is connected to an isolation

signal Visolate and the transistor source is connected to a capacitor **20** (Csensor) for storing a charge representative of the light incident on the photosensor **10**. The capacitor **20** has one terminal connected to the given voltage terminal of the photosensor **10** and another terminal that is connected to the drain of a reset transistor **32**. The reset transistor **32**, capacitor **20**, and isolation transistor **30** comprise the detection circuit **11**. An external periodic reset signal drives the gate of the reset transistor **32** and the source of the reset transistor **32** is fixed to some known voltage (shown as Vdd) capable of charging the capacitor **20** when the reset signal turns on the reset transistor **32**. The detection circuit **11** and the photosensor **10** form the photosensor circuit **12**.

The periodic reset signal will periodically cause the capacitor **20** to charge to a known voltage, specified by Vdd and the reset transistor **32** characteristics. When the reset signal is charging the capacitor **20**, the isolation transistor **30** is also turned on, thereby charging the photosensor **10** as well. While the capacitor **20** and photosensor **10** is charged, the output of the detection circuit is invalid, that is, it is not representative of the light incident on the phototransistor. After the reset signal is turned off, the photosensor **10** and the capacitor **20** are connected in parallel and, as light impinges on the photosensor **10**, the capacitor **20** and the photosensor **10** discharge together through the isolation transistor **30** over time to produce a photo signal representative of the total flux of light incident on the photosensor **10** during an integration period between reset signals. After the integration period, the capacitor **20** and photosensor **10** will have a charge representative of the cumulative light incident on the photosensor during the integration period. The charge is inversely proportional to the ambient light incident on the photosensor **10**, thus if more light is present, the charge will be smaller; if less light is present, the charge will be greater. The integrated light signal is measured because a periodic, integrated light signal collected over time is much more sensitive than a design that simply measures the instantaneous current from a photosensor.

The averaging circuit **14** includes a transfer transistor **34** whose gate is connected to a periodic transfer signal. A source of the transfer transistor

34 is connected to the sensor capacitor **20** and receives the photo signal. The drain of the transfer transistor **34** is connected to one terminal of an averaging capacitor **22**. The other terminal of the averaging capacitor **22** is connected to the given voltage (e.g. ground). The transfer transistor **34** and the averaging capacitor **22** comprise a storage circuit **13** for an average photo signal.

At the end of the light integration time period, the isolation transistor **30** is turned off and the transfer transistor is turned on. The charge on the sensor capacitor **20** is then combined with the charge on the averaging capacitor **22** to form a charge representing an average signal. If the capacitors are equal in value, the charge will be the average of the charge on the two capacitors. If not, the average charge will be the ratio of the relative capacitor sizes and charges. When the capacitor charges are redistributed and the voltage across both capacitors is equal, the transfer transistor **34** is turned off and the reset and isolation transistors (**32** and **30**) are turned on and the cycle begins again.

The output circuit **16** includes an output transistor **36** whose gate is connected to the averaging capacitor **22**. The source is connected to a resistive load that is connected to a power signal such as Vdd to form an output signal **40** representative of the ambient illumination incident on the photosensor **10**. The drain can be connected to a given voltage. As configured, the output circuit provides an inverting amplifier whose input is the average signal representing a continuous running average of the successive photo signals and that produces an average ambient light signal output. When the charge stored in the capacitor **22** is large enough to cause the output transistor **36** to turn on, the output signal will be connected to the given voltage. When the charge stored in the capacitor **22** is smaller, the output transistor **36** will have an increasing impedance and the average ambient light signal **40** will increase up to the limit of the power signal, e.g. Vdd.

When the photosensor circuit is first powered up, the ambient light falling on the photosensor **10** is unknown, as is the charge in the capacitors and the value of the output signal. After an initial cycle, the charge in the sensor capacitor **20** will correctly represent the ambient illumination incident on the

photosensor **10** and will be transferred to the averaging capacitor **22**. At this point, the voltage across the averaging capacitor **22** will not necessarily be equivalent to the voltage across the sensor capacitor **20** at the end of the light integration cycle but will be closer than before the charge transfer from the sensor capacitor **20**. The voltage across the averaging capacitor **22** will, in fact, represent the average charge in the sensor capacitor **20** and the averaging capacitor **22** weighted by the relative sizes of the capacitors **20** and **22** and the charge originally stored in them. At each subsequent cycle, the voltage across the averaging capacitor **22** will come closer to the voltage across the sensor capacitor **20** as charge is transferred to or from the averaging capacitor **22**. Eventually, the voltage across both capacitors will be the same. After each cycle, the averaging capacitor **22** will store the average of the charge in the sensor capacitor **20** and the previous charge in the averaging capacitor **22** (weighted by capacitor size). Thus, the charge in the averaging capacitor **22** represents a continuous running average of the charges stored in successive cycles within the sensor capacitor **20**.

If the ambient light on the photosensor **10** changes, the charge in the sensor capacitor **20** will change and the voltage across the averaging capacitor will also change to match. Note that the averaging capacitor **22** does not need an explicit reset or charge deposition into a known state. Instead, the charge on the averaging capacitor **22** gradually assumes the correct value as charge is transferred from the sensor capacitor **20**. Hence, the output from the output circuit **16** is always valid and gradually assumes the correct value without creating abrupt discontinuous changes. Moreover, the output signal provides a continuous, analog signal that is representative of the ambient illumination over a wide range, limited by the saturation of the sensor capacitor **20** in bright conditions, and by the minimum output transistor **36** threshold voltage. By modifying the sizes of the capacitors **20** and **22**, the sensitivity range of the circuit to ambient light may be modified and by changing the ratio of the capacitor sizes, the extent of averaging can be controlled.

The timing signals for this circuit are illustrated in Fig. 3, where T represents the length of time the signals are applied in the states indicated.

The transfer and isolate signals driving the transfer transistor **34** and isolate transistor **30** respectively, are inverses of each other; that is, one signal is the inverse of the other. Therefore, the signals can be derived from a single signal, preferably the isolation signal. An inverse signal is readily created using a circuit like the output circuit **16** having a transistor whose gate is connected to the signal, drain is connected to a known voltage such as a ground, and whose source is connected through a load to a power signal.

It is also possible to simplify the circuit of Fig. 2 by eliminating the isolation transistor **30** and isolate signal. In this case, while the transfer transistor **34** is on, the sensor capacitor **20** and averaging capacitor **22** will continue to discharge, depending on the ambient light incident on the photosensor **10**. Thus, the voltage will vary more and the output will not be as stable.

Alternative photosensor circuits may be employed and are included in the present invention. For example, photo capacitors that charge in the presence of light may be employed to provide a photo signal. In this embodiment, a reset signal must be employed to periodically discharge the photo capacitor. Photo resistors, photodiodes, and phototransistors may also be employed to discharge a sensor capacitor.

The photosensor circuit of Figs. 1 and 2 may be employed in a display system as shown in Fig. 4. Referring to Fig. 4, a substrate **50** has an array of light emitting elements, for example OLEDs, in a display area **52** and a photosensor circuit **8** integrated on the substrate **50**. The photosensor circuit **8** provides an output signal **40** to a controller **44**. The controller **44** responds to the output signal **40** and an input signal **46** to produce a display signal **42** that drives the display.

The signal from a thin film photosensor **10** is directly related to the area that it covers and the ambient radiation incident upon it. By increasing the area of an integrated photosensor **10**, the output signal **40** from the circuit **8** may be increased without significantly increasing the size of the display.

A plurality of photosensors **10** can be electrically connected in common to provide one integrated photo signal or, alternatively, they can be

separately addressed or combine their output. A greater number or size of integrated photosensors **10** can increase the signal, thereby improving the responsiveness of the ambient light detection. Moreover, the signal will be more representative of the overall ambient illumination incident on the display since, if a portion of the display is shadowed, having several sensors can provide several signals that can be averaged to produce an overall average of the illumination incident on the display area. Indeed, the location and shape of any shadows falling upon the display area **52** may be determined to a limited extent, thereby providing further information that can be used to optimize the performance of the display.

The photosensor(s) **10** of the present invention are sensitive to the frequency distribution of the light incident upon the photosensor. This sensitivity is due to the absorption spectrum of the materials and to the structure of the layers used to construct the photosensor. The frequency sensitivity of the device may be modified by providing color filters between the photosensor and the ambient radiation. Such filters can be used to customize the ambient light response of the photosensor(s) **10**.

The present invention may be used in both top and bottom emitting OLED display structures. Thin film structures used for active matrix OLED displays may be employed to form the photosensors **10** and to provide circuitry **11** and **14** to generate and process suitable control signals for the photosensors **10**. The same power and control signal methods may be used to operate the display. There are also a variety of ways in which the photosensors can be connected that depend on various factors such as the layout of the display and the conductivity of the electrodes and signal lines.

The photosensor elements may be selected individually (as are the display pixel elements) or in groups. Existing address and signal lines may be used to select or reset elements using existing electronic control methods. Groups of photosensor elements can be joined either physically or logically to provide a measure of incident light over larger areas thus reducing both the specificity of the information and the need for supporting logic and interconnects.

It is also possible to use the present invention to obtain information concerning the color of the ambient illumination. By utilizing color filters located between the photosensor and the ambient light, the ambient light may be filtered. Color filter deposition techniques are well known in the art and have been publicly demonstrated for displays. If a plurality of photosensors are provided with different filters, the signals from the photosensors can be used to optimize the display, for example by adjusting the color or white point of the display. In this case only, photosensors with color filters of the same color would be connected in parallel.

The light emitting display may be an organic light emitting diode (OLED) display that includes multiple supporting layers such as light emitting layers, hole injection, hole transport, electron injection, and electron transport layers as is known in the art. The photosensor circuit **8** may be deposited in a common step with active matrix display circuitry and may include identical materials to simplify processing and manufacturing.

Any or all of the photosensor circuit **10**, the detector circuit **11**, and the averaging circuit **14** can be integrated directly onto the same substrate as the display device or it can be implemented externally to the display. In general, higher performance and greater accuracy can be achieved by integrating the circuitry directly with the display device but this may not be desirable for all display devices.

In a preferred embodiment, the invention is employed in a device that includes Organic Light Emitting Diodes (OLEDs) which are composed of small molecule or polymeric OLEDs as disclosed in but not limited to US 4,769,292, issued September 6, 1988 to Tang et al., and US 5,061,569, issued October 29, 1991 to VanSlyke et al. Many combinations and variations of organic light emitting displays can be used to fabricate such a device.

The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

PARTS LIST

8	circuit
10	photosensor
11	detection circuit
12	photosensor circuit
13	storage circuit
14	averaging circuit
16	output circuit
20	capacitor
22	averaging capacitor
30	isolation transistor
32	reset transistor
34	transfer transistor
36	output transistor
40	output signal
42	display signal
44	controller
46	input signal
50	substrate
52	display area